Robotic Systems

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LONG-TERM GOALS

Teleoperated platforms being introduced into the field are expected to assume a larger role in the access and neutralization of area denial and explosive devices. This work includes examination, identification, and disposal of ordnance. These manipulators that consist of a base platform and a multiple degree of freedom manipulator with end effector get carried to the work site by vehicles.

Current commercial and developmental arms are either too expensive for EOD use or do not have the flexibility and strength-to-weight ratio necessary for Render Safe Procedures (RSPs). Technologies that lead to serpentine manipulators and electrostrictive polymer (ESP) actuators will be explored in this effort. Manipulators using these technologies would provide the operator, who is out of harms way, with high dexterity, which makes it valuable for complex and obstructed environments that are often encountered.

OBJECTIVES

The key to development of the manipulator is a new actuation technology, an ESP artificial muscle that has been developed at SRI. Muscle-like actuators based on this technology have the combination of high force-to-weight ratio, large stroke capability, good speed of response, and high efficiency unavailable in other actuation technologies. The use of such actuators will allow for the development

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of an extremely lightweight and slender manipulator with a sufficient number of degrees of freedom to negotiate motion around obstacles. Manipulators using these actuators are expected to be inexpensive, efficient, and reliable. Our objective is to develop this technology to the point that a highly dexterous serpentine manipulator with a "follow the leader" control methodology can be realized for EOD access missions.

APPROACH

A breakthrough is needed to reduce the cost for a high strength, high dexterity, low cost manipulator. A promising technical approach to this problem is the use of ESPs as actuators. Thin snake-like manipulators with a high number of degrees of freedom that would be capable of positioning an end-effector in a highly cluttered environment are not available. The main obstacle to their development has been the lack of lightweight and compact actuators capable of producing the needed forces (or torque), displacements, and speed of response. Many multi-articulated arm designs have placed the actuators on the manipulator base to avoid the issue of actuator size and mass.

One can readily see the advantage of muscle-like actuators by noting the many biological analogs to highly articulated dexterous manipulators that operate using muscular actuation. These biological manipulators include snakes, worms, caterpillars, centipedes and millipedes, eels, elephant trunks, octopus and squid tentacles, and prehensile tails of monkeys and other mammals.

SRI has been investigating ESPs for several years. They are presently developing muscle-like actuators based on this technology for applications in small-pipe-inspection robots (< 2-cm diameter). In addition, an ongoing effort is developing ESP transducers for underwater sound generation.

In essence, a rubbery polymer is sandwiched between two compliant electrodes. When a voltage difference between the two electrodes is applied, the resulting electrostatic force compresses the thickness and expands the area of the polymer film. Both the compression in thickness and the expansion in length or width of the film can be used for actuation. The effective pressures that can be generated with electrostrictive muscle can be very large. Polyurethane, for example, has demonstrated pressures up to 1.9 MPa (285 psi). These values are much larger than those suggested by the breakdown voltages quoted in industrial literature. The key to achieving higher breakdown voltages is to use high-quality thin films, and eliminate any remaining electrical defects prior to operation.

As noted, the pressures produced in the actuation of the polymer muscle can be quite high in certain polymers. The resulting strains may also be quite large. Strains of over 10 percent have been produced in a variety of polymers with moduli of elasticity ranging from 0.4 to 17 Mpa. Silicone rubber has produced the largest strains at over 30 percent in thickness. Note that while it is desirable to maximize the dielectric constant of the material, other factors, such as dielectric strength and uniformity of thickness of the film, may determine the magnitude of the electrostrictive response.

After a review of other technologies by SRI, not shown here, we conclude that ESP artificial muscle is an ideal actuator for snake-like manipulator as required by EOD applications. We have also begun to investigate the potential of using these actuators in small robotic platforms, especially legged propulsion vehicles.

Beyond the improved actuator research, we have investigated control methodologies for implementation of a “follow-the-leader” path for the end effector tip to snake around obstacles; the development and implementation of planning and control strategies for highly redundant serial link manipulators; and configuration and mechanical design of actuators and joints. The most challenging technical issue is the guidance of the arm in real time and in three dimensions by the remote EOD technician. A portion of this work studies the interface between the EOD Technician and the manipulator.

WORK COMPLETED

A mockup serpentine arm was fabricated which had a practicable geometry for our needs; and the correct design range of speeds for the arm to perform our work. An improved test bed has been developed with the same basic geometry as the mockup, but more degrees of freedom (14), greater degree-of-motion in the joints of the arm, and sufficient joint torque for manipulation at the end effector extremity of the arm for the following rendering safe tools: voltage and current measurement probes, wire cutters, stereoscopic video means, and shields for denial devices.

The serpentine arm test bed enabled examination of the following: control algorithms and computer codes developed for control of the serpentine arm; the concept of “virtual reality” guidance of the arm by the user; and the feasibility/patency of the sophisticated follow-the-leader serpentine arm entry and withdrawal. It was determined that the major drawback of the system is the large size of the arm which is a direct result of the lack of actuators with high strength-to-weight ratio and need for refinement of the controller. An effort to develop higher strength-to-weight ratio actuators was initiated as a result of studies with the test bed serpentine arm.

The Office of Naval Research has funded a one-year effort headed by Professor Howie Choset of Carnegie Mellon University in Pittsburgh to correct the software deficiencies of the test bed. The serpentine arm was delivered to Dr. Choset and his graduate students in July.

During FY98, SRI concentrated on fabrication of large rolls and tubular actuators and the means to achieve better electrostrictive materials for construction of these devices. After a legged locomotion analysis, SRI is now exploring fabrication of a new "spider" design for an actuator. A new dynamic analyzer test system is in the process of being assembled for faster and more accurate evaluation of electrostrictive materials.

Fabrication of large rolls and tubular actuators involved a stacking method based on an aluminum sacrificial layer, a dipping method employing Sylgard 182, a silicone rubber, and an offset electrode approach. Both curing and pinhole defect problems were overcome.

SRI continued synthesis of polymer films of Sylgard 182 doped with quaternary ammonium salts and high dielectric ceramic powders. SRI evaluated and measured the dielectric constants of fluorinated polyethylene, lead magnesium niobate, barium titanate, polyepichlorohydrin, and polychloroprene. SRI is documenting their work in increasing the dielectric constant of various films in order to advance the art of artificial muscle strength.

Presently, SRI is investigating Dr. Zhang's work at Pennsylvania State University on modified polyvinylidene fluoride (PVDF) ESPs that may offer greater energy densities. Further, SRI work has involved: colloidal suspensions of conductive polymers by Dr. Pei, who is a polymer chemist and is a recent addition to the SRI staff; charge transfer complexes; charge distribution layers; screen printing techniques; ionic conducting polymer gel film actuators; particle-to-particle connectivity in ceramic doped polymers; high-premittivity ceramic powders and fabrication of hydrostatically pressed pellets; a double-layer capacitance approach; and evaluation of new electrode materials.

A Record of Disclosure of Invention, *Navy Case Number 79541*, that describes a robotic arm of tubular type construction to maximize its moment of inertia for maximum lifting has been submitted. Use and application of microelectromechanical systems (MEMS) and artificial muscle technologies are described. The disclosure is based upon a test-bed assembly that utilized nylon "tendons" and pneumatic tubing as muscle. The following problem areas that were encountered in the fabrication and testing of the serpentine arm at the Pacific Northwest National Laboratories (PNNL) served as guidelines for the design considerations embodied in the patent disclosure: (1) extreme stresses in arm components resulting in the procurement of exotic materials; (2) non-existing or minimal load lifting capabilities; (3) inability of the serpentine arm to routinely return back to a null position due to a complicated positioning system; and (4) arm deflection and vibration susceptibility. Further, the patent disclosure provides a design that may lead to dividing arm control and arm manipulation into two separate entities. The disclosure contains the elements believed necessary to achieve a practicable tool that utilizes artificial muscle and MEMS technology for use in the EOD arena.

RESULTS

The fabrication of a spherical joint for use in a motor design with various large roll configurations pointed out the need for a new design approach. Designs to demonstrate practicable artificial muscle actuators are being investigated.

SRI improved their fabrication techniques for large rolls and tubular actuators using Sylgard 182 by employing a sacrificial layer of aluminum on mylar technique. Sylgard curing problems were solved by fabrication of larger rolls. Fabrication of these rolls into spherical joint actuators/links in quadrimorph or trimorph configurations with and without a rigid spine pointed out the need for a new design approach.

SRI also developed tubular actuators that were made by dip-coating electrodes and polymer from solution onto a sacrificial aluminum mandrel. This new fabrication technique gave better force and stroke output for the tubular actuators than previous methods.

Based on the above spherical joint experiments, a new design of actuator known as the “Spider” was fabricated. The new design provides better coupling of the actuation energy to the output. Spiders have produced an energy density of 0.004 J/g, 4 times the energy density of comparable rolls.

IMPACT/APPLICATIONS

There is a specialized need for an arm that can move precisely inside of an object without contacting any surfaces. Arm control must be precise, slow, and deliberate. The inadvertent bumping, or even

touching, of the arm into bomb components, electronics, or structure may have disastrous results. Therefore, the EOD technician must be able to spatially determine the exact location of the arm during an RSP. Further, the arm must operate at a slow or “sloth speed.” A computer will keep track of where the arm has been and, therefore, where it may not deviate to when it is withdrawn.

If developed, an artificial muscle, electrostrictive material construction, would have a vast array of applications that would serve as prime movers for: “sloth” type serpentine arms; a small legged vehicle for EOD use; inexpensive bomb disablement and UXO retrieval robots; and artificial prostheses.

TRANSITIONS

This technology will transition to both conventional EOD Joint Service programs and for specialized mission groups that support the Army’s 52nd Ordnance Group.

The technology for polymer muscles will be transitioned to ongoing EOD programs to enhance actuator performance and reduce cost.

RELATED PROJECTS

Teleoperated systems, Standard EOD robot and the Remote Controlled Transporter (RCT), have been fielded for limited use by EOD Technicians. These limits are partially due to the limited dexterity and strength of the manipulator.

The Jet Propulsion Laboratory’s Rover and Telerobotics Program, sponsored by the National Aeronautics and Space Administration (NASA) has a research program that is dedicated to the development of actuation technology based on ESP materials and actuation mechanisms are being developed in the form of “muscles.”

Virginia Polytechnic Institute has a project to develop a movable truss for NASA-Langley. This work is under review for application to this effort. The Defense Advanced Research Projects Agency and the Army have designed and/or built serpentine manipulators. They will not meet the environmental requirements of EOD, but some aspects of the technologies have application to this effort.

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PUBLICATIONS

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